

PROSPECTS FOR HERMES RUN II

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Data taking for Run II of the HERMES experiment will start in late 2001 with three main physics objectives for the next 4-5 years: a measurement of transversity distributions, an improved measurement of helicity distributions, and measurements of exclusive reactions to access Generalized Parton Distributions.

1 Introduction

The HERMES experiment ¹ at DESY Hamburg, Germany, combines a forward spectrometer with an internal gas target in the 27.5 GeV lepton ring of the HERA electron(positron)-proton collider. In between a pair of spin rotators enclosing the experiment the circulating self-polarized electrons (or positrons) get their transverse polarization changed into a longitudinal one; both polarizations are permanently monitored. The open-ended storage cell allows for high target gas densities: 10^{14} nucl/cm² are reachable for polarized hydrogen and deuterium, while the density of unpolarized gases can be up to 100 times higher, limited by beam and spectrometer conditions.

Systems of drift chambers before and after the 1.3 Tm dipole spectrometer magnet yield a tracking resolution of $\delta p/p \simeq 1\%$. Together with a set of scintillator hodoscopes the lead-glass electromagnetic calorimeter is used for high efficiency triggering of electrons and positrons. In conjunction with a TRD, a preshower and a Cerenkov detector it also allows for an efficient lepton-hadron separation. The Cerenkov detector was upgraded in 1998 from a threshold to a RICH detector ², now delivering pion/kaon/proton separation over most of the momentum range, $2 < p < 16$ GeV.

Over 40 millions DIS events (after data quality cuts), corresponding to an integrated luminosity of almost 1 fb^{-1} , were collected at HERMES in the years 1995-2000. About one third was taken with a (longitudinally) polarized target: 2.5 M on helium-3 (1995), 2.5 M on hydrogen (1996-97) and 8.5 M on deuterium (1998-2000). Two thirds of the data originate from several unpolarized target gases, ranging in atomic number from hydrogen to krypton.

Originally, the main physics goal of HERMES was the study of polarized semi-inclusive deep inelastic scattering (SIDIS). This led to a novel feature

of the HERMES experiment, as compared to earlier measurements at CERN, namely its capability to identify outgoing hadrons in addition to the scattered lepton. To reduce the systematic uncertainties of spin asymmetry measurements, the orientations of target (if polarized) and beam spin are regularly flipped, whereby the time scale for spin flips is seconds for the former and weeks for the latter.

As a first major physics result the helicity distributions of u - and d -quarks were precisely determined over the full accessible range, $0.023 < x < 0.6$, while a corresponding separation for sea quarks remains an issue. The accuracy attainable at HERMES after the inclusion of all already collected and future data are discussed in sect. 3. The SIDIS data can be analyzed more differentially, especially the azimuthal dependence of (beam or target) single-spin asymmetries for produced hadrons can be studied. This in principle opens access to a variety of ‘new’, i.e. hitherto unmeasured, chirally-odd parton distribution and fragmentation functions; prospects are discussed in sect. 2. The study of exclusive reactions attained particular theoretical interest in the last few years; they appear to be a potentially well-suited experimental tool to study Generalized (or Skewed) Parton Distributions, GPDs (SPDs). At HERMES, (quasi-) exclusive particle production is accessible thanks to the good hadron and photon detection capabilities of the spectrometer. Prospects for future HERMES data on exclusive reactions are presented in sect. 4.

2 Measurement of Transversity Distributions

A quark of given flavour in the nucleon is characterized by three independent twist-2 quark distributions: the well-measured number density distribution $q(x)$, the helicity distribution $\Delta q(x)$ measured by now for valence quarks, and the hitherto unmeasured transversity distribution $\delta q(x)$ that characterizes the distribution of the quark’s transverse spin in a transversely polarized nucleon. A complete understanding of the nucleon structure on the twist-2 level requires precise experimental data for all three functions.

Quark couplings with gluons and photons preserve chirality, i.e. observables have to be chirally even. Hence the chirally-odd transversity distributions should enter in combination with other chirally-odd objects in the corresponding expressions. It turns out that such combinations occur in several different SIDIS processes³, but not in inclusive DIS.

As a representative SIDIS example pion production by an unpolarized beam on a transversely polarized target is considered. The following $\sin(\phi)$ -weighted single target-spin asymmetry⁴ provides access to the quark transversity distributions via the Collins effect:

$$A_T(x, y, z) \equiv \frac{\int d\phi^\ell \int d^2 P_{h\perp} \frac{|P_{h\perp}|}{zM_h} \sin(\phi_s^\ell + \phi_h^\ell) (d\sigma^\uparrow - d\sigma^\downarrow)}{\int d\phi^\ell \int d^2 P_{h\perp} (d\sigma^\uparrow + d\sigma^\downarrow)}. \quad (1)$$

Here x , y and z are the standard SIDIS variables and $P_{h\perp}$ is the pion's transverse momentum. The azimuthal angles are defined in transverse space giving the orientation of the hadron plane ($\phi_h^\ell = \phi_h - \phi^\ell$) or spin vector ($\phi_s^\ell = \phi_s - \phi^\ell$) with respect to the azimuthal orientation of the lepton plane (ϕ^ℓ). For the calculation of the expected statistical accuracies the asymmetry (1) can be estimated from

$$A_T(x, y, z) = P_T \cdot D_{nn} \cdot \frac{\sum_q e_q^2 \delta q(x) H_1^{\perp(1)q}(z)}{\sum_q e_q^2 q(x) D_1^q(z)}, \quad (2)$$

and P_T is the target polarization, $D_{nn}(y)$ the virtual photon transverse spin transfer coefficient, $H_1^{\perp(1)q}(z)$ the T-odd polarized 'Collins' fragmentation function and $D_1^q(z)$ the usual unpolarized fragmentation function.

A sine-shaped single target-spin asymmetry with a magnitude of about 2% was extracted from 1996-1997 HERMES data collected on a longitudinally polarized proton target⁵. It has been interpreted in terms of the existence of a non-zero 'Collins' function $H_1^{\perp(1)q}(z)$, in conjunction with a non-zero transversity distribution. Using instead a *transversely* polarized proton target, the size of transverse spin phenomena is expected to grow by almost one order of magnitude.

To calculate prospects for future HERMES running the assumption of u -quark dominance can be used to determine e.g. the expected asymmetry $A_T^{\pi^+}(x)$ ¹³. In this case the asymmetry for a proton target reduces to

$$A_T^{\pi^+}(x, y, z) = P_T \cdot D_{nn} \cdot \frac{\delta u(x)}{u(x)} \cdot \frac{H_1^{\perp(1)u}(z)}{D_1^u(z)}, \quad (3)$$

and the approach of Ref.⁴ can be adopted to estimate $H_1^{\perp(1)u}(z)/D_1^u(z)$. The factorized form of Eq. (3) with respect to x and z allows the simultaneous reconstruction of the shape for both unknown functions $\delta u(x)$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$ if measurements of the asymmetry are done in (x, z) bins. The relative normalization cannot be fixed without further assumption. Since differences between $\delta q(x)$ and $\Delta q(x)$ are expected to be smallest in the region of intermediate and large values of x ¹³, $\delta q(x_0) = \Delta q(x_0)$ at $x_0 = 0.25$ has been assumed to resolve the normalization ambiguity.

Based upon a statistics of 7 million reconstructed DIS (Monte Carlo) events, corresponding to about 150 nb⁻¹, the projections for a measurement

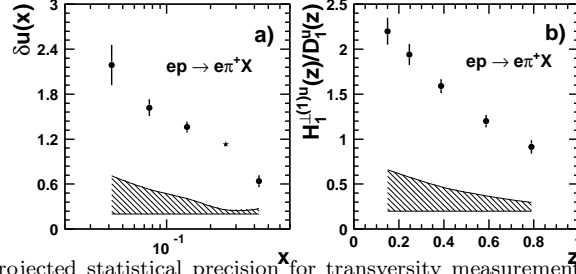


Figure 1. Projected statistical precision for transversity measurements on a transversely polarized proton target: a) transversity distribution $\delta u(x)$, b) ratio of fragmentation functions $H_1^{\perp(1)u}(z)/D_1^u(z)$. The star in a) shows the normalization point. The error bars correspond to an assumed data sample of 7 million DIS events. The hatched bands show projected systematic uncertainties due to the normalization and the u -quark dominance assumptions.

of $\delta u(x)$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$ through π^+ production at HERMES have been calculated¹³ for a mean target polarization of $P_T = 75\%$, as shown in Fig. 1.

3 Improved Measurement of Helicity Distributions

Access to quark helicity distributions requires both beam and target to be longitudinally polarized. The measurement of double-spin cross section asymmetries in inclusive DIS directly allows for the extraction of g_1 , the longitudinal spin structure function which represents a given combination of quark helicity distributions (for a recent review see e.g. Ref. ⁶). To disentangle the helicity distributions of individual quark flavours more observables are required. Of particular interest are independent measurements of double-spin asymmetries for the production of different hadrons h in SIDIS:

$$A_1^h(x, z) = \sum_q \left[\frac{e_q^2 q(x) \cdot D_1^{q,h}(z)}{\sum_{q'} e_{q'}^2 q'(x) \cdot D_1^{q',h}(z)} \right] \cdot \frac{\Delta q(x)}{q(x)} \quad (4)$$

The quantity enclosed in brackets is the purity $\mathcal{P}_q^h(x, z)$, representing the probability that a quark $q(x)$ was struck when a hadron h is detected. The underlying quark-hadron transition is described by the fragmentation function $D_1^{q,h}(z)$. It is assumed that the fragmentation of longitudinally polarized quarks is spin independent. Hence purities can be obtained from Monte Carlo calculations based on the same assumption.

Combining DIS and SIDIS asymmetries for different targets, a fitting procedure is used to determine the polarizations $\frac{\Delta q}{q}$ of individual quark flavours (for more details of the formalism see Ref. ⁷). Quark flavours with low relative abundance, as all sea contributions, require a relatively large amount of

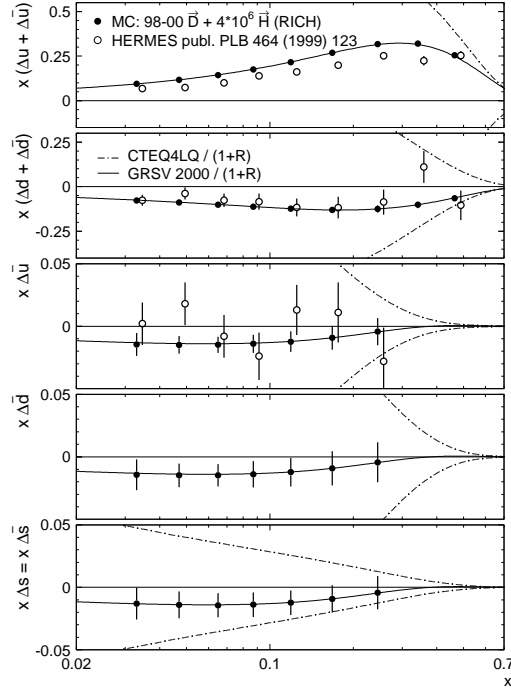


Figure 2. Projected statistical accuracies for individual quark flavour helicity distributions on the basis of the full 1996-2000 HERMES statistics plus one additional year of running with a longitudinally polarized proton target (closed circles). The published HERMES results, derived from the 1995-1997 data, are also shown (open circles).

statistics for the individual determination of their helicity distribution.

The most recent HERMES results are discussed in Ref. ⁷. This analysis is preliminary and the statistics, on which it is based upon (it includes only part of the deuterium data already collected), are still insufficient for a precise determination of individual sea quark helicity distributions. Even when the total available statistics will have been analyzed, it will be difficult to draw unambiguous conclusions on the polarization of the strange sea, Δs . Also, a discrimination between different theoretical models for the flavour asymmetry of the polarized light sea, $\Delta\bar{u} - \Delta\bar{d}$, will remain difficult.

A considerable improvement could be reached by running HERMES another year with a longitudinally polarized proton target. The then existing total data set, a mixture of real and MC data, was fitted as mentioned before using 0.45 as mean value for the combined beam and target polarization ⁸. As can be seen from Fig. 2 (closed symbols), the expected statistical accuracy looks very promising.

4 Measurement of Exclusive Reactions to Access GPDs

In the recent past a strong interest has emerged in Generalized Parton Distributions⁹, a set of non-perturbative process-independent distribution functions describing simultaneously different hard processes from inclusive to hard exclusive scattering. Due to the good capabilities of the HERMES spectrometer outgoing photons as well as pseudo-scalar and vector mesons can be detected in a large variety of (quasi-) exclusive reactions. The relevant exclusive channels are illustrated in Fig. 3 in conjunction with the quark GPDs (one per flavour) that are in principle accessible.

DVCS	$\gamma^* \mathbf{p} \longrightarrow \gamma \mathbf{p}$	$\mathbf{H} \quad \tilde{\mathbf{H}} \quad \mathbf{E} \quad \tilde{\mathbf{E}}$
exclusive pseudoscalar meson production	$\gamma^* \mathbf{p} \longrightarrow \pi^0 \mathbf{p}$ $\gamma^* \mathbf{p} \longrightarrow \pi^+ \mathbf{n}$	$\tilde{\mathbf{H}} \quad \tilde{\mathbf{E}}$
exclusive vector meson production	$\gamma^* \mathbf{p} \longrightarrow \rho^0 \mathbf{p}$ $\gamma^* \mathbf{p} \longrightarrow \omega \mathbf{p}$ $\gamma^* \mathbf{p} \longrightarrow \phi \mathbf{p}$	$\mathbf{H} \quad \mathbf{E}$

Figure 3. Hard exclusive processes accessible through HERMES in conjunction with the involved Generalized Parton Distributions.

Deeply-Virtual Compton Scattering (DVCS) offers the most direct connection between theory and experiment, since no fragmentation is involved. At HERMES energies the experimentally indistinguishable Bethe-Heitler (BH) process has a comparable cross section and hence allows the study of DVCS through their interference. From 1996/97 HERMES data on quasi-exclusive photon production a sine-shaped single beam-spin asymmetry with a magnitude of about 20% has been extracted very recently¹⁰ (cf. fig. 5 left). It shows the beam-helicity dependence expected from BH-DVCS interference.

Having both beam and target unpolarized, the DVCS lepton charge asymmetry¹¹ $A_{ch} \sim d\sigma(e^+p) - d\sigma(e^-p)$ exhibits a cosine behaviour in ϕ_γ , the azimuthal orientation of the $\gamma - \gamma^*$ -plane w.r.t. the lepton plane,

$$A_{ch} \sim \cos(\phi_\gamma) \times \text{Re} \left\{ F_1 \mathcal{H}_1 + \frac{x}{2-x} (F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2} F_2 \mathcal{E}_1 \right\}, \quad (5)$$

allowing access to the real parts of the DVCS amplitudes \mathcal{H}_1 and $\tilde{\mathcal{H}}_1$, while \mathcal{E}_1 is suppressed. Bjorken- x and t -channel momentum-transfer are denoted by x and Δ^2 , mass and form factors of the proton by M and F_i , respectively.

The helicity of the polarized positron (or electron) beam of HERA is re-

gularly changed to minimize systematic uncertainties. In conjunction with an unpolarized target the DVCS lepton helicity asymmetry ¹¹ $A_{LU} \sim d\sigma(e^+p) - d\sigma(e^-p)$ becomes accessible. It exhibits a $\sin\phi_\gamma$ -behaviour,

$$A_{LU} \sim \sin(\phi_\gamma) \times \text{Im} \left\{ F_1 \mathcal{H}_1 + \frac{x}{2-x} (F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{\Delta^2}{4M^2} F_2 \mathcal{E}_1 \right\}, \quad (6)$$

allowing access to the imaginary parts of \mathcal{H}_1 and $\tilde{\mathcal{H}}_1$.

The real and imaginary parts of the DVCS amplitudes $\mathcal{H}_1, \tilde{\mathcal{H}}_1, \mathcal{E}_1, \tilde{\mathcal{E}}_1$ are convolutions of known coefficient functions with the 4 different quark GPDs H, \tilde{H}, E and \tilde{E} (see e.g. Ref. ¹¹) shown in Fig. 3. Their extraction from a set of asymmetries measured in different reactions is a complex task for which no proven recipe exists as of today.

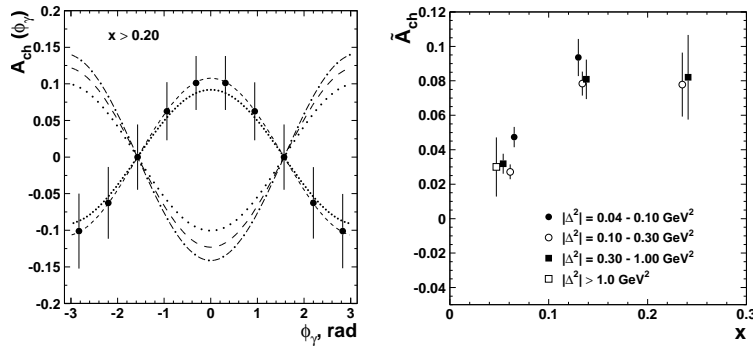


Figure 4. Projected statistical accuracies for a HERMES measurement of the lepton charge asymmetry in DVCS (unpolarized beam, unpolarized target). Left panel: ϕ_γ -dependence of A_{ch} . The curves correspond to different choices of GPDs. Right panel: x - and Δ^2 -dependence of A_{ch} , see text. The error bars are based on an assumed data set of 2 fb^{-1} .

At present the missing mass resolution of the HERMES spectrometer is preventing an experimental exclusion of low-lying excited nucleon states (Δ isobars). Plans exist to add a Recoil Detector to the experiment to clearly identify exclusive events. High statistics data sets on exclusive photon, pion and meson production are expected from future running with a high density unpolarized target allowing for an annual integrated luminosity of 2 fb^{-1} .

Based upon this experimental scenario the leading twist-2 formalism has been used to determine prospects for future DVCS measurements ¹² taking into account the acceptance for all involved particles. The expected statistical accuracies are shown in Fig. 4 for the lepton charge asymmetry A_{ch} , and in Fig. 5 for the lepton helicity asymmetry A_{LU} . The left panels show the azimuthal dependence. The right ones display the anticipated de-

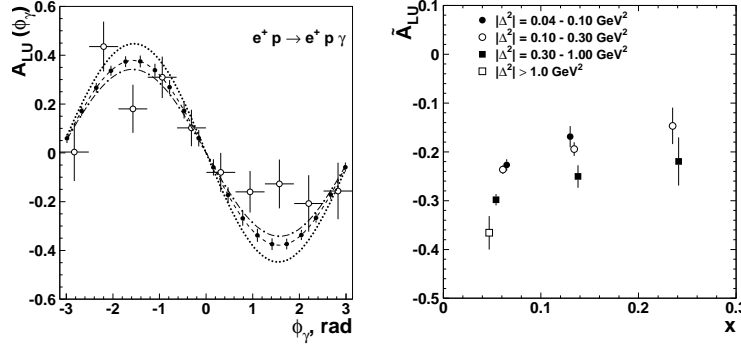


Figure 5. As previous figure, but for the lepton helicity asymmetry A_{LU} (polarized beam, unpolarized target). Open circles in left panel are existing HERMES data (see text).

pendence on x and Δ^2 , presented for \tilde{A}_{LU} , the difference between asymmetry integrals over appropriate ϕ_γ -hemispheres. Clearly, the ansatz for the GPDs directly influences the size of the asymmetry⁹. The Δ^2 -dependence will become experimentally accessible at HERMES through the new Recoil Detector.

5 Conclusions

The main physics objectives for the next 5 years of HERMES running have been sketched: Measurements of SIDIS using transversely and longitudinally polarized proton targets, and of exclusive reactions using unpolarized targets. Information on several hitherto unknown quantities will be provided to shed light on different new aspects of the nucleon (spin) structure.

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